White Design Associates embodied CO_2 analysis of a secondary school

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ABSTRACT: This paper describes the process, challenges and results of a carbon profiling tool used as part of the design process at White Design Associates.

The paper first explores the need amongst designers for a carbon profiling tool to enable and encourage a focus on carbon reduction, as a key element in the fight against global warming. Next it describes the methodology adopted by White Design Associates to develop a tool to be used throughout the building design process, to inform design decisions, and begin to quantify the climate change impact of the finished building.

Examples from the most recent iteration of the tool, used during the construction of John Ferneley College, illustrate the development of the tool, the challenges that were faced, and the 'headline' results of the analysis. It also illustrates how White Design incorporated the results into the curriculum through web updates and highlights the Carbon Stacks visualisation tool.

Keywords – Carbon profiling, embodied carbon, John Ferneley College, school curriculum, White Design Associates, carbon dioxide.

fig. 1 Main entrance; John Ferneley College; completed 2010

1. INTRODUCTION – IDENTIFYING A NEED FOR CARBON PROFILING

Emissions from the built environment account for approximately 45% of total energy consumption in the UK (CIBSE, 2004). Of this 45% it is generally assumed that carbon dioxide emissions from operational energy are four to five times greater than the emissions generated by constructing new and refurbishing buildings. This suggests that operational emissions are far more important than construction emissions. However, updated standards stipulated in building regulations, design guides, demands from funding and commissioning bodies have focused on improving buildings' operational performance to an extent that this ratio is shifting. As architects and engineers design buildings with lower operational impact, the relative impact of embodied energy and carbon dioxide (CO_2) emissions becomes more significant over the life-cycle of the building. A similar report, '*Sturgis Associates LLP Indicative Whole Life Carbon Emissions*' (2010, RICS Research) shows the the percentage of operational CO_2 emissions shifting from 30% for housing constructed in 2010, to 95% in housing constructed in ten years time. Understanding the whole life carbon picture of an individual building is essential when considering future targets. Indeed the study of John Ferneley College showed that the whole life CO_2 emissions of the building (embodied CO_2 + operational CO_2 emissions) would equate to a total of 10,580 tonnes over a 60-year lifespan. Embodied CO_2 makes up just over one fifth of this - a significant contribution to lifetime impact that needs consideration throughout the design process.

In 2004, White Design researchers identified in an internal paper '*Research needs and opportunities to support architectural work at White Design'*, (Ciotti, L 2007) a need to identify the key sources of carbon dioxide emissions within the material supply chain. They did this by testing the material specification choices being made by the design team, as part of a feedback process to continuously improve in-house design quality. Early experience was gained in retrospectively calculating the embodied energy of two built projects: the 'Rethinking School', a prototype 'slice' through a typical school that was open to visitors for two years at the Building Research Establishment 'Innovation Park'; and Dalby Forest Visitor Centre. A range of data retrieving methodologies were adopted, both as a means of exploring the generic data available, and to reflect the specific material choices that were made in the procurement of the buildings. A report, *'Embodied Global Warming Potential and the Re-Thinking School at BRE.'* (Collins, D. 2008) was produced outlining findings in conjunction with Future Conversations.

Skills and outcomes from these projects informed the development of White Design's carbon profiling tool, designed to serve the needs of both the design team and client. The tool meets a demand from the user to better understand the carbon footprint of their project and can be used by the wider project team to influence the design decisions being made as the project unfolds.

The profiling tool has been used to assess the embodied CO_2 of the materials used in the building of John Ferneley College, in Melton Mowbray, Leicestershire. In 2008 Leicester CC commissioned WDA to design a new 800 place secondary school building and associated landscape to replace the existing John Ferneley High School in Melton Mowbray. On the back of WDA's acquired expertise, this forward-thinking County Council had the foresight to commission an adjoining study on the embodied carbon dioxide of principle construction materials. By involving the whole design team of architects and consultants, contractor (Willmott Dixon) and the key stakeholders, the client is given the opportunity to contextualise material choices through the design and construction phases of the build. The report was produced in 2010, entitled *'John Ferneley College: Embodied Carbon Dioxide Analysis.'* (Bramley, R. 2010). The aim of the analysis is to gather and assess information regarding the embodied CO_2 content of a number of commonly used building materials and elements over a defined lifetime. The aim is to enable key players to do the following:

- Understand the relative significance of embodied CO_2 in key material and specification choices as part of any building life-cycle
- Design buildings with a lower environmental impact
- Influence design choice to minimise embodied and operational carbon load
- Compare embodied CO_2 to operational CO_2 from building use (operational energy)
- Develop a benchmark for our buildings and reduce CO_2 on an ongoing basis
- Provide educational tools and curriculum links, such as can be found on the John Ferneley website

2. JOHN FERNELEY COLLEGE CASE STUDY

The design proposals set out to produce a school that would be an exemplar of sustainable design and construction. This ethos informs aspects such as its orientation on site, the selection of natural materials and the use of natural ventilation, day lighting techniques and landscaping concept. The building achieved a BREEAM 'Very Good' and EPC 'B' rating.
The college is split into 5 learning zones arranged along an internal ‘street’. Each zone is themed and set around a shared LRC/ICT facility, passively watched over by staff work rooms and open plan unisex toilet facilities.

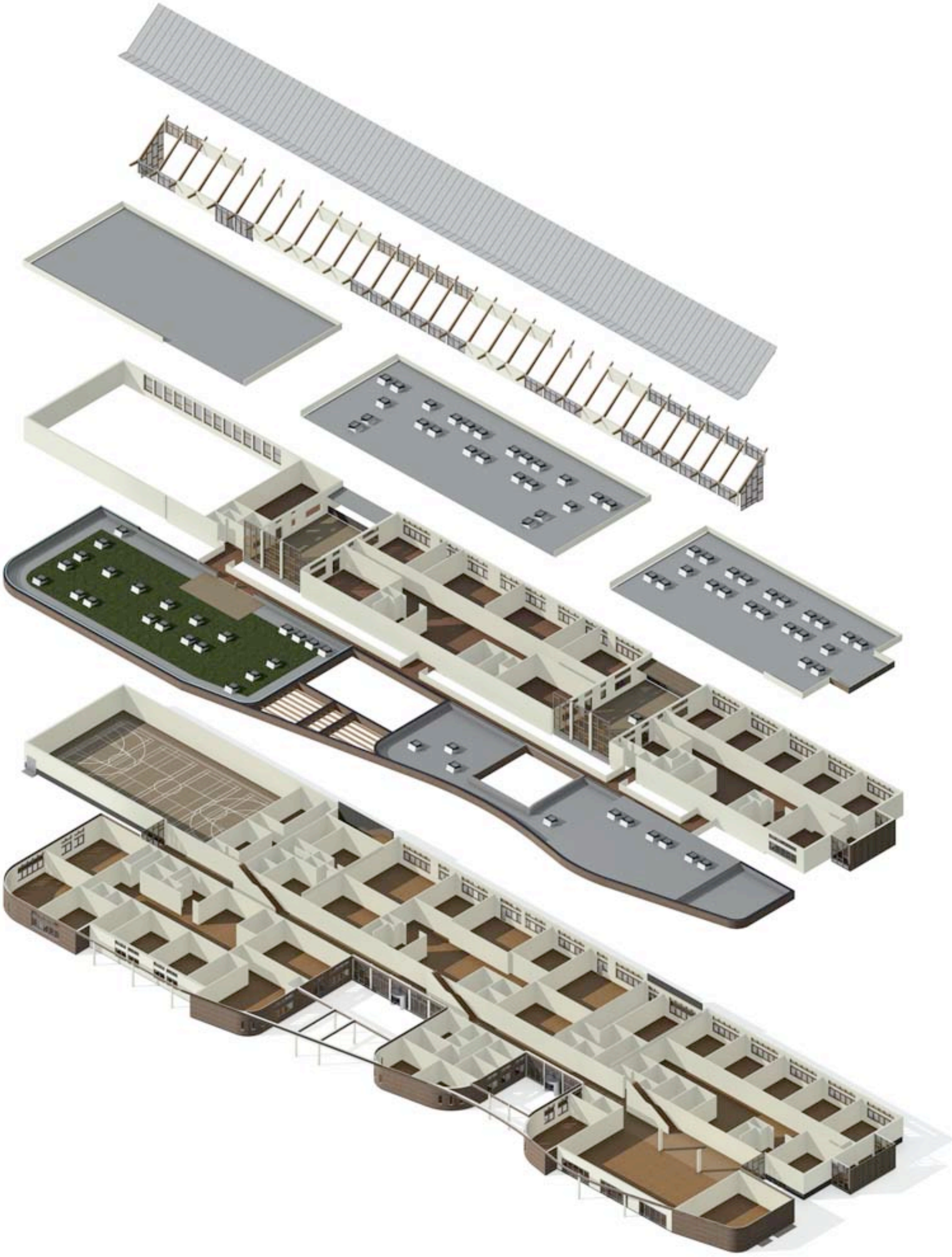

fig 2: Spilt axonometric of John Ferneley College.

Carbon consumption has been reduced by over 60%, incorporating sound passive strategies alongside appropriate renewable energy technologies, including low energy star rated computers, 85% efficient lighting with daylight dimming and 450kw wood pellet biomass heating. Meters provide 'live' energy generation and grey water consumption from the 25kw wind turbine and rainwater harvesting systems allowing the building to become a teaching and learning tool.

fig 3. Construction photograph of the energy centre, John Ferneley College.

3. SCOPE OF THE CARBON PROFILING TOOL

The software tool developed by research staff at White Design is designed to measure carbon dioxide embodied in construction materials by matching embodied carbon co-efficients against material quantity. The tool enables the user to observe the percentage of the total CO2 emissions a particular element comprises; observe emissions on a 'per square metre' basis, project a whole life Co2 impact using EPC emissions predictions; compare embodied emissions with operational emissions; and compare substitute materials.

The study of John Ferneley College focused on major building elements - structure, walls, foundations, floors, roof, underfloor heating system, and windows etc. However, there is scope for a much wider analysis, such as the inclusion of construction site processes, transport, landscape elements and so on. In this case, the main focus was building materials where there was expected carbon intensity and also the opportunity for mitigation by replacement with alternative products. The objective was to help designers, contractors and value engineers to make informed material choices that reduce both the embodied and operational impact of the building.

The scope of this study is to analyse embodied CO_2. However, White Design recognises that other factors must still be considered alongside this one. These include:

- Non-energy greenhouse emissions and environmental impacts
- Financial viability
- Operational energy and performance
- The life span of materials and building components
- Social, cultural, aesthetic and heritage questions
- Material selection - recycled content levels, reuse of products, reduction of construction waste

These are outside the scope of the embodied CO_2 study but can be considered in a number of ways, such as lifecycle analysis, whole life costing, community consultation and through the use of toolkits such as Wrap's Recycled Content toolkit, the Building Research Establishment's BREEAM assessment method and the Code for Sustainable Homes.

4. METHODOLOGY

4.1 Choice of measurable unit

Focus has shifted from embodied energy to embodied CO_2. Embodied energy refers to the total energy used to manufacture a given product. It takes into account all energy in kilowatts used to make and extract a raw material and turn it into a finished product. Embodied CO_2 is more useful in showing climate change impact as it takes into account the actual carbon dioxide emitted as a result of the primary energy used in the manufacture process. For example, aluminium produced using energy from a coal fire power station has a much greater embodied CO_2 than if the aluminium was produced using renewable sources, like hydro-electric power.

Even more indicative is the embodied CO_2 equivalent (CO_2e) which takes into account all the other gases which contribute towards the greenhouse effect (like methane and nitrous oxide). CO_2e is a metric measure used to compare the emissions from various greenhouse gases based on how much they contribute towards global warming, that is their Global Warming Potential (GWP). Calculating CO2e or GWP has its own challenges as the data is not yet available for many building products. White Design decided at the outset to concentrate on embodied CO_2, rather than full CO2e or GWP data. The primary reason for this decision was access to data. As will be detailed later in the paper, the main dataset used by White Design during its CO_2 analyses is the Inventory of Carbon and Energy (ICE) published by the University of Bath (Hammond and Jones, 2008). The metric used in this inventory is embodied CO_2, therefore this was adopted as the default for the John Ferneley College analysis.

The following distinctions are made in the use of embodied carbon terminology:

Cradle-to-grave: This is the full Life Cycle Assessment from manufacture ('cradle') to use phase and disposal phase ('grave')

Cradle-to-gate and Cradle-to-site: This is an assessment of a partial product life cycle from manufacture ('cradle') to the factory gate (that is, before being transported to the consumer) or the building site. The use phase and disposal phase of the product are usually omitted.

Cradle to cradle: This is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process.

White Design have adopted the second definition for this analysis.

4.2 Material scope

In the example of John Ferneley College, the White Design carbon profiling tool provides an assessment on the "as built" building, rather than the building "as designed". Therefore the key to creating an accurate profile is access to “as built’ data. The research team at White Design Associates used the bill of quantities to make initial material profiles for analysis by the design team, “as designed”. This facilitates discussion around material substitution at the design stage as the toolkit can also be used as an estimation tool based on notional designs early in the design process, provided sufficient quantity data is available.

The final report comprised data collected direct from the site buying team, as and when orders arrived on site. Good relationships with the quantity surveyor, contractor, material suppliers and manufacturers are key, as it is the information they provide that enables the profile to take shape.

No assessment of embodied CO_2 can claim to be entirely accurate nor can it take into account every material, component, fixture and fitting of the completed building. This is because of the limited availability of accurate quantity and CO_2 data. Until such studies are commissioned, or such data is available, it is necessary to set certain boundaries regarding the building elements that are included in the embodied CO_2 assessment. This changes from project to project, depending on the needs of the design team and the client. It is also a cost issue, every material or component added to the analysis will have a time and cost implication. For the most recent study, John Ferneley College, White Design adopted an approach that focused on three areas: the major construction elements of structure, walls, foundations, floors, roof, underfloor heating system, windows, rooflights and doors; the carbon intensive and extensively used materials such as concrete, steel, and glass; and materials that offer opportunities for mitigation by replacing with alternative products.

This study did not include materials or components where there was limited scope for mitigation. Therefore mechanical and electrical (M & E) equipment such as electrical cabling and light fittings, were not included in the study. Previous research carried out by White Design on the BRE Innovation Park School and Dalby Forest Visitor Centre suggests that this current approach will capture approximately 85% of the CO_2 load of the building.

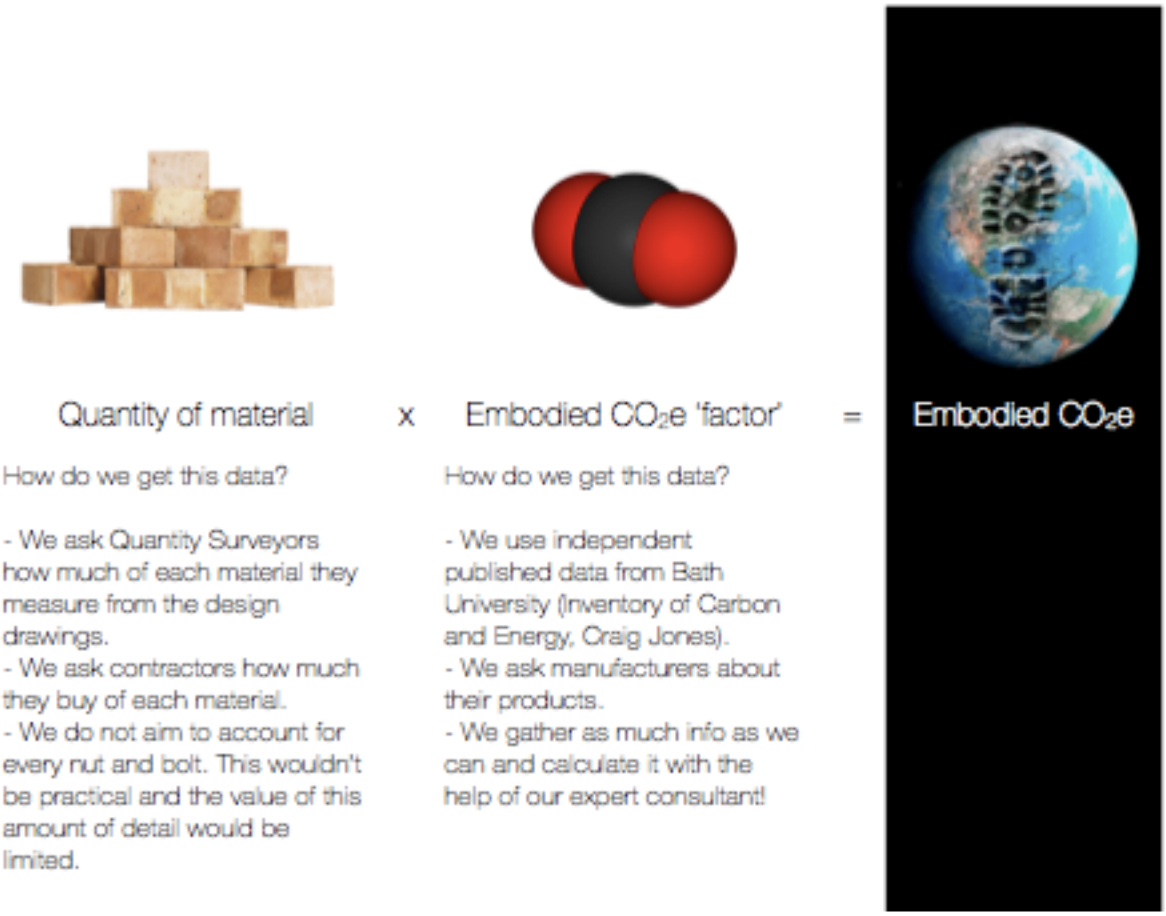

fig 4. Simple methodology equation.

4.3 Data source selection

The data required to carry out a CO_2 assessment is limited to a very few sources. Two main sources exist for the CO_2 factors used by White Design:

1. Independent Published Data

The major source of independent published data in the UK is the Inventory of Carbon and Energy (ICE) published by Bath University (ibid). Using the data ensures transparency as they are in the public realm. The downside to using standardised data is that they do not account for individual production processes of specific companies, but rather use a “broad brush” approach based on averaged data.

2. Supplier/Manufacturer data

Using data from suppliers and manufacturers is sometimes the best option for ‘new’ or unusual materials. However, it is difficult to be sure of the parameters used by the companies in establishing their factors. This means that there is potential for bias and inconsistency. However, where the boundaries and parameters used for establishing CO_2 factors are known, then it can be the most appropriate data to use.

Both data sources were used for John Ferneley College. Major built elements such as the steel frame and concrete were calculated accurately by using actual material data and quantities in conjunction with the suppliers and manufacturers. Independent published data, principally from ICE, was used with all other materials and components where manufacturers and suppliers were not forthcoming with detailed CO_2 data. Complex components, where a number of different materials are present, were broken down into their component parts to give a list of materials, these were then analysed using ICE data.

The validity of any assessment of this type depends on the accuracy, relevance and completeness of the data and on the conversion factors used. White Design's approach is to set out as clearly as possible all the assumptions and conversion factors used to ensure transparency.

White Design is part of the Construction Emissions Community of Practice (CECoP), a group of life cycle assessment professionals whose aim is to develop a UK-wide, standardised set of accurate embodied CO_2 data. (www.cecop.org.uk) During the John Ferneley College project the assessors kept regular contact with CECoP and other consultants working in the field to ensure current methods and data were in use.

5. ACCURACY OF THE TOOL

This depends on two factors: the accuracy of material quantities and accuracy of the CO_2 conversion factor data.

For the scope and boundaries of CO_2 factor, the majority of the published data used in analysing embodied CO_2 adopts the cradle to site approach. This considers all energy use during the lifetime of a product from extraction of raw materials (including fuel) to the point at which the product reaches its point of use (the building site). Although the cradle to grave approach, including emissions in use, maintenance and end of life options, would give a more complete overview of the product's life, there is insufficient published data for this to be carried out at present. The impact of these latter life cycle stages can instead be assessed qualitatively in the meantime by considering the energy intensity of maintenance regimes and the potential for re-use or recycling.

For some materials, such as timber, the final life cycle stage is highly significant to their overall embodied CO_2 load. There is a lack of consensus about how timber and other bio-based building materials (such as hemp and wool), should be considered in terms of their embodied CO_2 e outputs. The major source of contention is whether bio-based materials should take into account the CO_2 sequestered in the material itself. As part of CECoP, White Design and other life cycle analysis professionals hope to answer questions relating to embodied impacts in building materials. This is in order to reach a UK-wide consensus and a standardised approach that is hereto lacking. During the John Ferneley project a timber workshop held by CECoP aimed to find consensus on how to treat timber products. Also during the life of the build, the UK published PAS 2050 (BSI, 2008), which has a bearing on how building products should account for their embodied CO_2.

A tonne of timber sequesters approximately 1850kg CO_2 e during its growth. Timber used in construction goes through a number of processes to turn it into a finished product. Using the data supplied in ICE we can develop a "negative" CO_2 factor for timber by subtracting the processing emissions from the sequestered CO_2 (Table 1).

	Sequestered CO2e kg CO2/kg	ICE data kgCO2/kg	Total CO2 factor
General timber	**-1.85**	0.46	-1.39
Sawn softwood	**-1.85**	0.45	-1.4
Sawn hardwood	**-1.85**	0.47	-1.38
Particle board	**-1.85**	0.51	-1.34

fig 5. Timber sequestered and total CO2 factors

The "carbon negative" figures above assume a cradle-to-site approach, where the end of life of the material is not considered. For cradle-to-grave footprints, i.e. "whole life" declarations, the footprint will depend on how long the product is in service and what happens to it at the end of its useful life: re-use; recycling; incineration with energy recovery; incineration without energy recovery; or landfill. If the end-of-life scenario within the 100 year assessment period is incineration then the timber will emit around 1800kg CO_2 per tonne - this more or less cancels out the benefits of sequestration. In the John Ferneley analysis using a "carbon negative" figure for timber products would have a small impact on the overall total for this school as timber is not extensively used, reducing it from 2000 tonnes to 1924 tonnes, a 3.8% reduction.

6. RESULTS OF THE CO_2 CALCULATOR TOOL AT JOHN FERNELEY COLLEGE

The assessment was carried out under 6 major headings covering the major built elements:

- Foundations
- Structure
- Floors
- Walls
- Windows; rooflights, doors
- Roof

These along with floor coverings, ceilings and the heating system make up the total tonnes of embodied CO_2 at John Ferneley College (Figure 1). The individual contribution of each of the material elements assessed is available in detail on the John Ferneley website (http://johnferneley.white-design.co.uk) and also in a report published by White Design (Bramley, 2010). The specification of material elements is listed in fig.6.

fig 6. Table of material elements assessed.

MATERIAL ELEMENTS ASSESSED				
Unreinforced concrete foundations C20 / 25: CEM IIIA+SR				Dryline battens - timber 85mm
Reinforced concrete foundations RC35 without slag				Skim plaster interior partitions
Reinforcement steel				Carpet

MATERIAL ELEMENTS ASSESSED				
Underfloor heating pipe Rotex polyurethane PE-X 25mm 15000 linear metres				Vinyl Forbo safestep
Underfloor heating insulation grid Rotex EPS 1.7kg per sqm				Vinyl Forbo surestep
underfloor heating Insulation grid Rotex EPS 1.4kg per sqm				Sprung floor (floorboards on battens and rubber)
Screed cemex supaflo				Sprung floor (floorboards on rubber backing)
Pre-cast concrete Coltman planks				Windows, Doors and Rooflights as per White Design drawings 6153F3201, 3203, 3204, 3205,
Steel wire in concrete floor slab				Rockfon Koral 600x600 mineral wool ceiling tiles
Steel Frame				Rockfon Hygiene mineral wool ceiling tiles
SIPS 150 mm thick				Sports panel acoustic panels 40mm thick. High density mineral wool
Concrete blocks 140mm thick 7.3 N/mm2 (7.3 MPa) enviroblock EV13 Recycled content: 86%.				Resin bonded fibre glass density 135kg/m3 Soundsorba tiles
Aluminium strip polyester powder coated parapet wall cladding (1mm)				Pre-cast concrete slabs
Timber cladding Cedar 22mm				Structural screed cemex supaflo
Permarock system Permarend insulating system (28mm Mineral Fibre ins board 2mm render coating)				Insulation Isover glasswool
Plasterboard interior partitions				TPO Roof Membrane 1mm
Isover glasswool blanket				Aluminium strip polyester powder coated parapet wall cladding
Plasterboard to dryline				Metal deck roof over street 1mm powder-coated aluminimu standing seam
SIPS 180mm				

Quantity data was obtained from the contractors' Quantity Surveyor team, directly from manufacturers and through analysis of architectural drawings. Unless otherwise stated the CO_2 data used was sourced from ICE.

It was decided that special emphasis would be given to concrete and steel, materials that are both carbon intensive and extensively used. Early in the design process an exercise was carried out to evaluate the merits of both concrete and steel framing solutions. The results showed that, in terms of embodied CO2, there were only minor differences between the two. The CO_2 conversion factors for these elements were developed in conjunction with Future Conversations Consultants (see website reference).

Total embodied CO_2 impact of John Ferneley School

The analysis at John Ferneley College concludes that **2,000 tonnes of CO_2** are embodied in the materials that make up the major built elements of the College. In order to make comparisons with other buildings it is useful to have a 'per square meter' figure, this is based on the Gross Internal Area of the building which is 292 kg CO_2e /m^2.

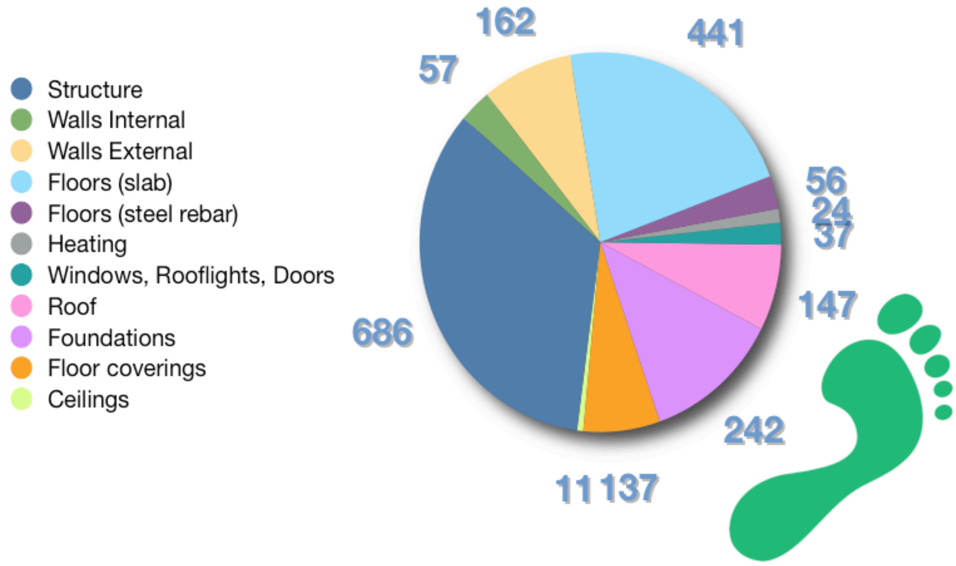

fig 7. Embodied Carbon Dioxide impact of building elements of John Ferneley College

Over half of the total is embodied in the frame and floor slab of the building. In fact, steel and concrete in the frame, floor and foundations, account for 1,425 tonnes of CO_2 , this represents **71%** of the total. The walls and the roof are the next biggest contributors with 11% and 7% respectively.

From this analysis, it is clear that most efforts to reduce the embodied impact of the John Ferneley building need to be concerned with the structure and foundations.

The elements described capture some 85% of the CO_2 footprint. If the M&E system, fixtures and fittings were also taken into account, the total tonnes would be closer to 2300 tonnes CO_2.

Comparison of Embodied and Operational CO_2 emissions

The Energy Performance Certificate (EPC) shows that the building is 'B rated' and has an emissions rate of 21.97kg CO_2/m^2 per annum. This is based on a useful floor area of 6486 m^2. Therefore a total annual operational CO_2 emission of 143 tonnes is expected.

Using this data the embodied CO_2 emissions are equivalent to 14 years of operational energy, given that the analysis showed that 2000 tonnes of CO_2 are embodied in the building.

The whole life CO_2 impact over a 60 year life span is:

Whole Life CO_2 impact = embodied + operational CO_2

= 2,000 + (143 * 60)

= **10,580 tonnes CO_2 over 60 years**

Therefore the embodied CO_2 impact represents almost 20% of the total impact over a 60 year life span.

7. CONCLUSIONS AND RECOMMENDATIONS

Even when a final figure for the embodied CO_2 impact for John Ferneley College has been calculated, there is still work to be done to ensure this number is meaningful, tangible and relevant.

At present the end result is at least as important as the process. It is the process of carrying out the study that forces design teams to make design choices, and educates all members of the project team about the embodied impact of their material, design and site choices. Nevertheless, it is useful to be able to display and share the result with other interested parties. For this reason White Design has developed a number of ways to display the embodied CO_2 impact of the building, particularly when considering links to the curriculum and using the analysis as an educational tool and in promoting it on the John Ferneley College website.

White Design created the website to illustrate the construction process and keep interested parties informed about progress on site. It was also seen as an opportunity to provide curriculum links and to illustrate the findings of the CO_2 analysis as it was being carried out. By following the link to Environmental Research and the Energy Index the details of the CO_2 analysis are available. In addition to final figures, this section also provides some interesting information and tips relating to the construction of John Ferneley College. It is hoped that these will be accessed by staff and pupils and can become part of the school curriculum.

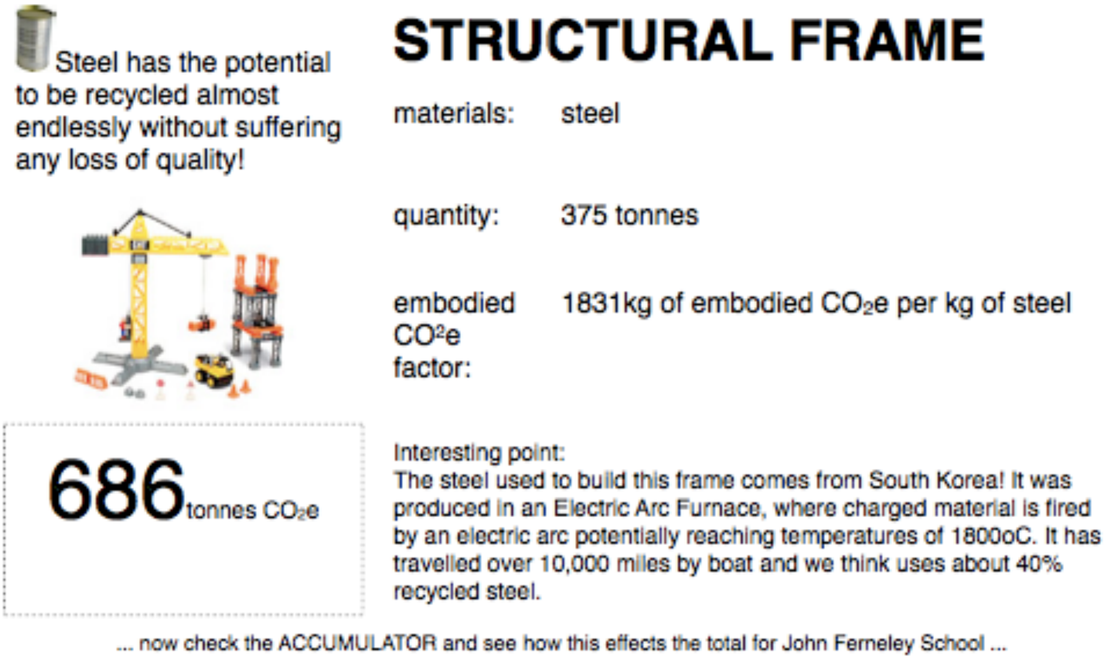

fig 8. A webpage featuring steel from the JF college website, showing additional information about steel manufacture generally and specific to the project.

Gas is a rather intangible material and most people find it difficult to visualise a tonne of CO_2. By converting tonnage of CO_2 into volume we can then use a number of methods to make the result more visually relevant:

Hot Air Balloons: by taking an average sized hot air balloon we can quantify the amount of CO_2 gas embodied in John Ferneley College, equivalent to 503 hot air balloons.

fig 9. Hot air balloons above Bristol

Carbon Stacks: How does John Ferneley College stack up in terms of carbon dioxide? If we take the total tonnage of CO_2 emitted by the construction of the school we get a figure of 2000 tonnes. But what does this look like? Each tonne of CO_2 occupies a volume of 556 cubic metres. If we spread out the total volume of CO_2 over the footprint of the school we end up with a stack of CO_2 almost 230 metres tall. This is equivalent to approximately 60 storeys.

The tallest structure in London is the 50 storey One Canada Square, which rises 235 metres (771 ft) in Canary Wharf. The Carbon Stack is proportionally accurate, allowing website users to see which elements of the building have most impact, and how each element adds to the whole. (http://johnferneley.white-design.co.uk/).

It is hoped that this analogy and the whole process of analysing the relative impacts of materials will provide useful in terms of connecting the construction process of the building to its use by students within the College's curriculum. It is also hoped that the work has a greater relevance and interest to others undertaking similar work, and also as an educational tool for students, in helping them prepare for their future, discussing the role and the importance of carbon reduction in their learning environment.

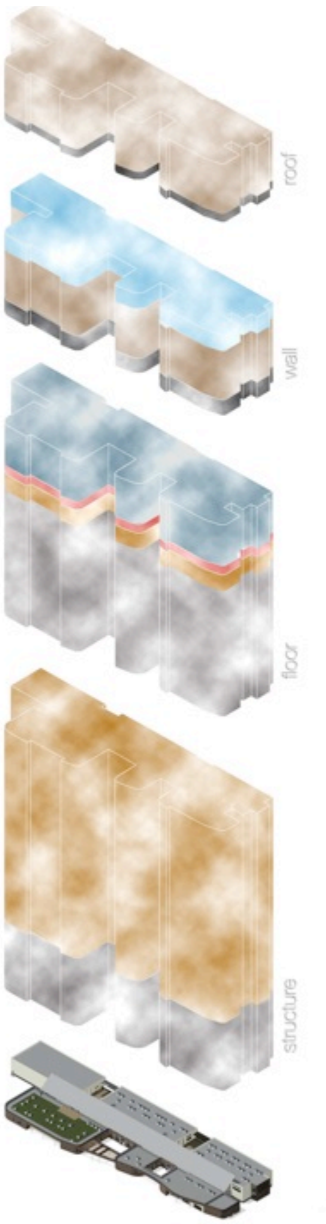

fig 10. Carbon stacks TM represents 60 storeys of carbon dioxide stacked above the footprint of John Ferneley College - the equivlent of a volume of 556 cubic metres.

7. REFERENCES

Bramley, R. (2008) Calculating the embodied Carbon Dioxide of White Design buildings. Internal Briefing Note, White Design Associates, Bristol

Bramley, R. (2010), John Ferneley College: Embodied Carbon Dioxide Analysis. White Design Associates Report, Bristol

British Standards Institute (2008), Guide to PAS 2050: How to assess the carbon footprint of goods and services. BSI and Carbon Trust, Crown, London

Collins, D. (2008) Embodied Global Warming Potential and the Re-Thinking School at BRE. Prepared for White Design and Re-Thinking by future conversations, London.

Construction Emissions Community of Practice (CECoP) www.cecop.org.uk

CIBSE (2004), Energy Efficiency in Buildings. CIBSE Guide F. Chartered Institution of Building Services Engineers, London

Ciotti, L. (2007) Research needs and opportunities to support architectural work at White Design. White Design Associates Report, Bristol.

Future Conversations Consultants www.future-conversations.com

Hammond, G. and Jones, C., (2008), Inventory of Carbon & Energy (ICE) Version 1.6a, University of Bath, Bath

John Ferneley College website: http://johnferneley.white-design.co.uk White Design Associates, Bristol

Sturgis Associates LLP. (2010), Carbon Profiling as a solution to whole life Carbon emission measurement in buildings. RICS, London